CAN COSMOLOGICAL CONSTANT BE A FORBIDDEN ZONE (GAP) IN QUANTUM VACUUM

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Abstract

In this work we suggest, without detailed mathematical analysis, a hypothesis on the physical meaning of cosmological constant. It is primarily based on a conceptual analogy with energy characteristics of the crystal lattice structure, i.e. energy zones theory in solid state physics. Namely, according to some theories (holographic principle, emergent gravity etc.) it is supposed that empty space, i.e. quantum vacuum holds a structure like to crystal lattice. It implies a possibility of the existence of totally occupied zones consisting of many levels of the negative energies as well as at least one negative energy forbidden zone, i.e. negative energy gap without any (occupied or empty) level of the negative energy. We suppose that given negative energy forbidden zone in the quantum vacuum represents effectively a positive energy zone without quantum particles that corresponds to cosmological constant. Also we suggest some other (less extravagant) model of the cosmological constant. Here cosmological constant is usually considered as the effect of the quantum vacuum fluctuations where problem of the cut-off can be solved quite simply since here integration over unlimited domain of the quasi-momentums must be changed by integration over one, finite "Brillouin zone".

It seems that recent astronomical data on the universe acceleration are in the best agreement with theoretical predictions on the cosmological constant that can be considered as energy of the (quantum) vacuum [1], [2]. Nevertheless physical meaning of the non-gravitational (anti-gravitational) vacuum energy is quite mysterious [3]-[6]. This "Mystery of the Millennium" [3] implies "Crying Need for Some Bright Ideas"[4].

In this work we shall suggest, without detailed theoretical formalism, a hypothesis on the physical meaning of cosmological constant. It is primarily based on a conceptual analogy with energy characteristics of the crystal lattice structure, i.e. energy zones theory in solid state physics. Namely, as it is well-known, in some theories of the quantum gravitation, e.g. in theories of the holographic principle [7]-[11] or emergent gravity [12], etc., there is supposition that (gravitational) vacuum has a space structure similar to a three-dimensional spin lattice with distance between

sides proportional to Planck length. "Let us temporarily suppose the world is a 3 dimensional lattice of spin like degrees of freedom. For definiteness assume the lattice spacing is the Planck length lP and that each site is occupied with a spin which can be in one of two states. For example a lattice fermion field theory would be of this type." [8]

Given supposition we shall consider and further extend, conceptually but without detailed mathematical analysis, in this work. We shall suppose that empty space, precisely (gravitational) vacuum has really a lattice structure like a solid state crystal lattice. Also, we shall suppose that given (gravitational) vacuum lattice holds a dynamics similar, at least conceptually, to the quantum dynamics of a solid state crystal structure. It can imply a possibility of the formation of totally occupied zones consisting of many discrete levels with negative energies as well as at least one negative energy forbidden zone, i.e. negative energy gap without any (occupied or empty) level of the negative energy. Finally, we shall suppose that given negative energy forbidden zone in quantum vacuum represents effectively a positive energy zone without quantum particles that corresponds to cosmological constant. Also we shall suggest some other (less extravagant) model of the cosmological constant. In this alternative model cosmological constant is usually considered as the effect of the quantum vacuum fluctuations according to vacuum lattice structure. Here problem of the cut-off can be solved quite simply since integration over unlimited domain of the quasi-momentums must be changed by integration over one, finite "Brillouin zone".

Thus suppose that empty space, i.e. (gravitational) quantum vacuum has really a lattice structure like a solid state crystal lattice. Further, suppose that given vacuum lattice holds "unmovable" elements, individually denoted A, in lattice sides, that, practically, build given lattice, like to atoms in the solid state crystal lattice. Also, suppose that vacuum lattice holds "movable", at least formally, elements, individually denoted a, that represent fermions and that can move, at least formally, through given lattice like to electrons in the solid state crystals.

Suppose now that given vacuum lattice holds a dynamics similar, at least conceptually, to the quantum dynamics of a solid state crystal structure.

Suppose that in the first approximation given dynamics would be roughly presented as "motion" (at least in the formal sense) of a-s in a potential hole determined by A-s, i.e. by vacuum crystal lattice. Periodical potential of given vacuum lattice can cause that given potential hole can hold only discrete levels of the negative energy any of which, according to remarkable Dirac interpretation of the quantum vacuum, is completely occupied by two a-s representing fermions. For this reason there is no any "motion" of a-s through vacuum lattice. All this conceptually corresponds to approximation of the Fermi gas of the motion of electrons in the metals at 0 K temperature when all energy levels under Fermi level are completely occupied and when motion of the electrons is impossible.

We shall suppose that, in the more subtle description of the quantum vacuum lattice dynamics, dynamical interaction between A-s, i.e. lattice and a-s, induces splitting of the a-s negative energy levels and their grouping in the negative energy zones. Suppose, for reason of simplicity, that there are only two completely occupied, allowable negative energy zones, W_1 and W_2.

Suppose that give two allowable negative energy zones are discretely separated by one (for reason of simplicity we shall suppose that it is unique) negative energy gap, i.e. forbidden negative energy zone or zone without any level of negative energy W_g .

All this is, of course, conceptually analogous to the zone theory in the solid state physics.

Completely occupied, allowable negative energy zones W_1 and W_2 can be considered as usual parts of the quantum vacuum without any quantum "motion", i.e. transition from one in the other level within any of given zones. It is possible, of course, suppose that some external dynamical

interaction realizes transition of some a from W_1 or W_2 in the levels with positive energy so that, according to Dirac anti-matter interpretation, absence, i.e. hole of a in W_1 or W_2, can be effectively considered as an anti-particle with positive mass-energy. Quantum motion of the hole of a through W_1 or W_2 corresponds conceptually to quantum motion of the anti-particle through positive energy levels.

It is quite reasonable to be supposed that positive energy in form of quantum particle or anti-particle (including field quants) satisfies equivalence principle and gravitates.

Forbidden negative energy zone or zone without levels with negative energy, W_g, can be considered as an unusual part of the (gravitational) quantum vacuum. It needs an additional interpretation. Quantum system a from W_1 or W_2 or from any positive energy level cannot arise in W_g. Also, since W_g has not any (occupied or empty) energy level, there is no any dynamical interaction that can realize transition of a from W_g in W_1 or in W_2or in any positive energy level. It, roughly speaking, means that W_g has not any correct presentation by individual quantum particle or anti-particle. Nevertheless, in full spirit of the Dirac anti-matter interpretation, absence of the negative energy levels in W_g can be effectively considered as the presence of some kind of the positive energy.

It is quite reasonable to be supposed that positive energy without quantum particle or anti-particle corresponding to W_g acts anti-gravitationally. Indeed, roughly speaking, forbidden zone W_g forbids gravitational falling of a and other quantum particles or anti-particles in given domain of the negative energies.

Crystal lattice structure of the (gravitational) quantum vacuum can imply and some other (less extravagant) possibility for cosmological constant modeling. Namely, it can be again supposed that given vacuum lattice structure and corresponding periodical potential energy determine a translator symmetric dynamics like to Bloch-Brillouin dynamics in the quantum solid state physics. Then physical states can have form of the quasi-free waves corresponding to quantum fluctuations of the vacuum. Given waves , i.e. fluctuations can hold quasi-momentums (different, exactly speaking from usual momentums). Energy spectrum obtains then a zone structure since energy of the states is no more a completely continuous function of the quasi-momentums. Namely, then there are different allowable energy zones (any of which represents a continuous function of the quasi-momentums from corresponding finite intervals or "Brillouin zones") discretely separated by forbidden energy zones. In this case problem of the cut-off by defining of the cosmological constant by vacuum fluctuations [5] can be solved quite simply since here integration over unlimited domain of the quasi-momentums must be changed by integration over one, finite "Brillouin zone".

Finally, we can shortly conclude and repeat the following. In this work we suggested, without detailed mathematical analysis, a hypothesis on the physical meaning of cosmological constant. It is supposed that empty space, i.e. quantum vacuum holds a structure like to crystal lattice. It implies a possibility of the existence of totally occupied zones consisting of many levels of the negative energies as well as at least one negative energy forbidden zone, i.e. negative energy gap without any (occupied or empty) level of the negative energy. We supposed that given negative energy forbidden zone represents effectively a positive energy zone without quantum particles that corresponds to cosmological constant. Also we suggested an alternative model of the cosmological constant. In this model cosmological constant is usually considered as the effect of the quantum vacuum fluctuations according to vacuum lattice structure. Here problem of the cut-off can be solved quite simply since integration over unlimited domain of the quasi-momentums must be changed by integration over one, finite "Brillouin zone".

This work is dedicated to memory of Mica Mali.

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